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LIFE CYCLE ASSESSMENT OF PRECAST AND CAST-IN-SITU CONSTRUCTION

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Abstract

Prefabrication is a sustainable construction method to provide better quality control, improved site safety and a reduction of the construction time and labour demand as compared with the traditional cast-in-situ construction. Hong Kong is a mega city with over 40,000 buildings and limited land area. The adoption of precast concrete in building constructions has become more and more frequent in both public and private sectors.

This study aims to compare the environmental impacts of precast and cast-in-situ construction methods through life cycle assessment. A typical private residential building project in Hong Kong is selected as both precast and cast-in-situ methods are used to construct the residential buildings. The comparison is carried out for the functional unit of a concrete façade element of the studied project. The scope of the study is to cover the processes from 'cradle to end of construction', including material extraction, manufacturing, transportation, and on-site construction.

It is found that the precast façade performs 6.3% better than the cast-in-situ façade in terms of the carbon emissions. The carbon emission for the precast façade is 647 kg CO_2 eq, while the figure is 708 kg CO_2 eq for the cast-in-situ façade. Based on the research findings, it is recommended to adopt precast concrete in building constructions. The industry should consider the carbon reduction as a benefit to implement precast concrete.

Keywords:

Carbon emissions; Hong Kong; Life cycle assessment; Precast concrete; Prefabrication

1 INTRODUCTION

Prefabrication is a process of manufacturing to assemble various materials to form a component part of the final installation at a specialized facility [1] . In Hong Kong, precast concrete has been adopted since the mid-1980s in public residential buildings developed by the Hong Kong Housing Authority (HKHA) [2]. Public and private housing both hold about half the population in Hong Kong. In recent years, precast concrete has been more and more frequently used in private residential buildings, which is encouraged by the gross floor area (GFA) concession [3].

The adoption of precast concrete can largely reduce the on-site construction waste, time and labour, as well as improve the quality of construction [4]. As reported by previous studies, precast constructions can lead to a reduction of 52% of construction waste and 70% timber formwork [5]. The environmental benefits of precast constructions are also investigated by [6, 7]. While these studies only focused on the public sector, the environmental benefits of precast

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concrete in the private sector have yet to be studied.

This research aims at comparing the environmental influence by adopting precast concrete in the private residential building sector. The precast façade element in a typical private residential building in Hong Kong is studied. Carbon emissions of precast façades and cast-in-situ façades are estimated using life cycle assessment (LCA). Project data is collected through questionnaire surveys and interviews. The analysis covers 'cradle-to-end of construction' life cycle stages. Suggestions to the construction industry are provided based on the research findings.

2 METHODS

The studied building is a high-rise residential building in Hong Kong to provide about 3,500 apartments. The buildings are 30-35 floors with eight apartments on one floor. A photo of the studied project is shown in Fig. 1. The project applies a precast façade that represent about 6% of the total concrete volume. In this study, a precast façade element in the studied project is compared with a hypothetical cast-in-situ façade element.

Fig. 1: The studied high-rise private residential building project (the photo is provided by developer).

The study system encompasses the 'cradle-to-end of construction' processes regarding a concrete façade element, including material extraction, transportation, manufacturing, and on-site construction. The functional unit for comparison is one concrete façade element.

The project data is collected through a questionnaire survey addressed to the precast manufacturer. The questionnaire is to collect the information about the energy and water consumption of the precast façade, as well as the waste generation within the precast yard. Another questionnaire for the on-site construction is delivered to the project manager for the information of construction waste, equipment use, energy consumption and waste generation within the construction site. In addition, drawings and electricity bills are solicited from the contractor. Semi-structured interviews are conducted with project managers to further validate the collected data. To establish the LCA model, the Ecoinvent database is adopted to provide secondary data of upstream processes.

The precast yards to produce precast elements for the construction site in Hong Kong are located in Pearl River Delta in mainland China (outside Hong Kong). The transportation of precast elements is one of the key contributors to carbon emissions. The transportation details relevant to the studied building are given in Table 1. The details of the model inputs are given in Table 2. The electricity consumption to produce one precast façade at precast yard is 53 kWh, and the electricity consumption to install one precast façade on the construction site is 21 kWh. On the other hand, the electricity used for a cast-in-situ concrete façade on-site is 66 kWh. Lifting and installing façade elements consumes diesel, and it is estimated that one precast façade uses 12 L diesel, while one cast-in-situ uses 8 L diesel during manufacturing and on-site activities.

The LCA model is established in SimaPro 8. The model is composed of over one hundred project processes. Both the project data and secondary data from databases are used in the model. Since data from different regions are apparently different in terms of their value and quality [8], the model tried to incorporate the local information to offset this unavoidable discrepancy of LCA. The life cycle impact assessment (LCIA) method of Greenhouse Gas Protocol [9] is applied to calculate the carbon emissions of the two scenarios. The method was developed by the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBSCD) based on the global warming potential (GWP) factors proposed by IPCC.

Material	***Country of origin***	***Distance***	***Transport method***
Concrete mix	HKSAR	25 km	Concrete mixer
Cement	China	150 km	Truck 20-28 t
	China	150 km	Truck 20-28 t
Aggregate	China	150 km	Truck 20-28 t
	China	80 km	Truck 20-28 t
Precast concrete	China	150 km	Truck 20-28 t

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Reinforcing steel	China	100 km	Truck 20-28 t
	China	250 km	Truck 20-28 t
Formwork steel	China	200 km	Truck 3.5-20 t
Formwork timber	China	250 km	Truck 20-28 t
Window glass	China	150 km	Truck 20-28 t

Table 1: Transportation details of the materials used in the high-rise residential building.

Item	***Unit***	***Façade element***	
		IS	***PC***
Cast-in-situ concrete	m^3	0.92	0
Precast concrete	m^3	0	0.92
Aluminium frame	m	12.5	12.5
Glass	kg	14.1	14.1
Tile	m^2	4.47	4.45
Transport glass	tkm	2.12	2.12
Transport precast	tkm	0	381

Table 2: Model inputs for the cast-in-situ (IS) and precast (PC) scenarios.

3 RESULTS

The comparison for the façade elements is given in Fig. 2. The façade element includes the materials of concrete, steel, aluminium, tiles, glass, etc. The as-built precast façade element emits 941 kg CO_2 eq, while the hypothetical IS scenario emits 1,005 kg CO_2 eq, which is 6.3% higher than PC scenario. The carbon emissions of 0.92 m^3 concrete in PC and IS scenarios are 647 kg CO_2 eq and 708 kg CO_2 eq, respectively.

The difference is mainly due to the different formwork types used in the two different concrete methods. The cast-in-situ construction adopts timber formwork, which can only be reused less than 10 times. On the other hand, the formwork used to produce precast is steel that can be reused over 100 times. To cast 1 m^3 concrete, 45.7 kg timber formwork is required for cast-in-situ concrete, while 14.5 kg steel formwork is used for precast concrete. The carbon emission of timber formwork to produce the same amount of concrete is considerably higher than that of steel formwork.

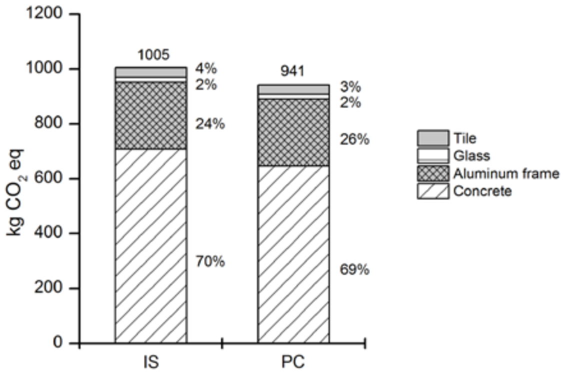

Fig. 2: Carbon emissions of concrete façade element (IS: cast-in-situ concrete; PC: precast concrete).

4 CONCLUSIONS

Carbon emissions of precast and cast-in-situ construction methods are compared using LCA. The model considers the ''cradle-to-end of construction" life cycle stages. The results show that the carbon emission of precast concrete is apparently lower than that of cast-in-situ concrete. The as-built precast façade element emits 941 kg CO_2 eq, while the hypothetical IS scenario emits 1,005 kg CO_2 eq, which is 6.3% higher than the PC scenario. This is primarily due to the difference in formwork types. The timber formwork which can be reused only less than 10 times emits more greenhouse gases than steel formwork. Based on the research findings, it is highly recommended to adopt precast concrete to contribute to a more sustainable construction industry.

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